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REVIEWS

*Experimental Investigation of the Formation of Minerals in an Igneous Magma.*¹ A review.

Professor Morozewicz has at length published in German the results of five years' elaborate experimentation on the synthesis of minerals and of volcanic rocks. This work is the most exhaustive of its kind since Fouqué and Lévy's epoch-making experiments, published in Paris in 1882. The wide scope and large scale of the experiments of Morozewicz, and the very complete chemical investigation of his products, together with carefully devised reference to the geological application, make this new work worthy of extended review and of careful study by geologists.

The motive of the experimenter was primarily to imitate, as nearly as possible, natural igneous magmas, and by fusion of carefully prepared chemical mixtures in a large glass furnace to produce crystalline masses in sufficient volume for isolation and chemical investigation of the component artificial minerals. The author lays stress upon the importance of more careful work in the chemistry of the silicates in mineralogy, and the chemistry of silicate mixtures or solutions in petrography. For the former the work of Lemberg and Thugutt is quoted as of primary importance, and for the latter Lagorio and Vogt have initiated methods of research that should be emulated for more complete understanding of the nature of igneous rocks. The work of Fouqué and M. Lévy was limited to microscopic investigation of the products of fusion in small platinum crucibles in the Fourquignon furnace. Morozewicz obtained the use of a corner in a large Siemens furnace, in a glass factory near Warsaw; the interior of this furnace is much of the time at white heat and continuously so for periods of weeks and months. The furnace is heated by a blast of carbonic monoxide mixed with air, and the temperature to which the crucibles were sub-

¹ JOSEF MOROZEWICZ (Warsaw). Experimentelle Untersuchungen über die Bildung der Minerale im Magma. Tschermak's Mineralog. u. Petrogr. Mittheilungen, Bd. XVIII, H. 1-2-3, pp. 1-90 and 105-240, 8 Plates, 1898.

jected was estimated to vary from 1600° down to 500° C. Two openings, half a foot long each, were arranged in the side of the furnace so that crucibles could easily be inserted and removed. The temperature within the entrance chamber was much less than in the heart of the furnace, and by placing a crucible first in the innermost glow, then at the inner mouth of the chamber, and lastly, a short distance within the chamber, conditions of gradual cooling and crystallization could be brought about. From day to day at certain periods there were variations in the temperature of the furnace itself due to the requirements of glass manufacture which went on as usual in the huge crucibles of the factory, and these changes affected to a certain extent the crystal structures obtained. Fire-clay crucibles of various sizes were used, the melting being done in large crucibles, the crystallization in smaller ones of 150 c. c. capacity. The crucibles when filled were carefully covered and placed on refractory tiles. They were first warmed to dark red heat and then thrust into the position of maximum temperature. After a few hours they were drawn to the second position at the inner mouth of the opening, and finally, after remaining there for several days were drawn within the small chamber where they finally cooled.

Crystallization lasted commonly from one to three weeks, but in exceptional cases the crucibles were left in the furnace as long as two and one half months. A few experiments were made on a very large scale in the great factory crucibles where over a hundred pounds of mineral matter was molten at a time. It was found that certain mixtures corroded the crucible violently, while others remained unaffected by contact with the crucible walls. Magmas with high magnesia and low alumina and alkalies acted violently upon the clay, because magnesia has, at these high temperatures, a very strong affinity for alumina, and in the absence of alumina from the mixture combines readily with that which forms the containing vessel. Mixtures of lime and the alkalies, rich in alumina, do not affect the crucible, even after long exposure to the highest temperatures. About two hundred experiments were made in all, and of these 25 per cent. failed owing to various causes. The others produced coarsely crystalline mineral masses in many cases, so that isolation of the minerals for analysis could be accomplished. The mixtures used were prepared usually from pure chemicals. Silica was used in the form of the hydrate $\text{SiO}_2 \cdot 3\text{H}_2\text{O}$; alumina as hydrargillite ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$); lime, magnesia, and the alkalies as carbon-

ates, iron oxide as hematite, and instead of ferrous iron was used either siderite (FeCO_3) or a fayalite-slag (Fe_2SiO_4).

The pulverized substances were intimately mingled and at first carefully heated to drive off the water. For the larger and coarser experiments common commercial mixtures were used, but in all cases the proportions were calculated as nearly as possible with reference to the known composition of igneous rocks. For a special group of experiments, combinations of minerals in theoretical proportion were prepared, in order to test the theory of solutions; the rock-forming silicates are conceived as capable of supersaturation of a magma, and, in proportion to their relative amounts and the nature of the solvent, crystallize out in the order of saturation; all the mineral products were carefully analyzed and the results were checked in each case by carefully sampled quantitative analysis of the mixture *after fusion*, in order that the effect of the addition of new silica or alumina from the crucible walls, by corrosion, might be allowed for. Finally, a special group of experiments involved the melting up of pieces of natural rocks, granite, andesite, basalt and others, and these experiments the author is still carrying on.

The following list will show the great variety of minerals produced by so-called "dry fusion" from silicate magmas:

1. OXIDES: Corundum, Hematite, Ilmenite, Quartz, Tridymite, and a peculiar prismatic variety of SiO_2 .
2. ALUMINATES and FERRATES: Spinel, Chlorospinel, Pleonast, Hercynite, Magnoferrite, Magnetite.
3. SILICATES: Sillimanite, Cordierite, Olivine, Forsterite, Fayalite, Monticellite, Enstatite, Hypersthene, Augite, Alkaline Augite, Pleo-chroic green Augite, Diopside, Wollastonite, Biotite, Lepidomelane, Sanidine, Labradorite, Anorthite, Melilite, Nepheline, Häüyne, Nosean, Sodalite, and Lagoriolite.

The following volcanic rocks were artificially produced: Rhyolite, with flow structures, spherulitic basalt-obsidian; enstatite-basalt with both intersertal-glassy and micro-porphyrific structures; normal basalt with micro-porphyrific structure; augitite with hyalopilitic ground-mass; melilite-basalt in both micro-porphyrific and granular forms; and häüyne rocks of intersertal-glassy and granular structures. From mixtures supersaturated with alumina were produced mineral aggregates bearing abundantly crystalline Al_2O_3 in the form of corundum and related minerals. Among these were a cordierite-andesite of glassy or

micro-porphyratic structure, and ophitic spinel-basalt, a spinel-bearing feldspathic basalt of micro-porphyratic and divergent-radial structure, a corundum-bearing nepheline-basalt, melilite-basalt bearing spinel, corundum-nephelinite, and coarsely trachytic corundum-bearing anorthite-nepheline mixtures.

Corundum and spinel have frequently been obtained synthetically by both "wet" and dry methods, and an examination of the literature, no less than the casual production of these minerals in preliminary experiments, showed that an excess of alumina readily induces the crystallization of free Al_2O_3 , in the form of corundum, and with relatively high magnesia and iron in addition, produces spinel. The minerals were isolated and analyzed; both green and black varieties of spinel were obtained, the one chlorospinel, the others pleonast and hercynite. A comparison of the magma analyses with the relative amounts of these minerals produced, shows that alumina plays the principal rôle in the production of spinel as well as corundum. On the hypothesis that the crystallization of free alumina indicates supersaturation, it was believed that precise saturation, or the condition of the magma after the excess of Al_2O_3 had crystallized out, should give a ratio of alumina to the bases of 1 : 1, that being a constant in most of the aluminosilicates (feldspar, nepheline, h  yne, sodalite, mica, etc.). This was confirmed by eight analyses of the glass from which the corundum and spinel had crystallized; these gave the ratios

$(\text{K}_2\text{O}-\text{Na}_2\text{O}-\text{CaO}) : \text{Al}_2\text{O}_3 : \text{SiO}_2 =$ (1b) 0.9 : 1 : 1.9; (2b) 0.9 : 1 : 2.3; (3b) 0.9 : 1 : 2.3; (4b) 0.9 : 1 : 2.3; (5b) 0.9 : 1 : 2.3; (6b) 1.2 : 1 : 1.9; (7b) 1.1 : 1 : 3.4; (8b) 1 : 1 : 3.2.

Thus with variable silica, the ratio of Al_2O_3 to the bases averaged = 1.

To confirm this result a special series of test mixtures were melted up and crystallized. These tests, made variously with magmas of the composition of basic and acid feldspars, with the alkalies and silica in varying proportions, and under varying conditions of cooling, gave the following important results:

1. A silicate magma is saturated with alumina, when the ratio of the bases to alumina is equal to 1.
2. Saturated aluminosilicate magmas of mixed composition and of varying silica contents, are capable at high temperatures of dissolving alumina and forming supersaturated solutions.
3. Pure soda-aluminosilicate magmas dissolve alumina in large

quantities; lime-magmas in small quantity and pure potash-magmas are, under the same conditions, incapable of dissolving alumina in excess.

4. Supersaturated aluminosilicate magmas, whether of mixed silicates or simple, with the general composition $\text{MeO} \cdot m\text{Al}_2\text{O}_3 \cdot n\text{SiO}_2$ ($\text{Me} = \text{K}_2, \text{Na}_2, \text{Ca}, n = 2 - 13$), throw out all the excess of alumina (over $m = 1$) in the form of corundum crystals, when magnesia and iron are absent, and n is less than 6; in the form of sillimanite (or sillimanite and corundum) when n is greater than 6; in the form of spinel (or spinel and corundum) when the magma is rich in magnesia and iron and n is less than 6; or in the form of cordierite (or cordierite and spinel) when Mg and Fe are present and n is greater than 6. In the last two cases sillimanite and corundum may also sometimes crystallize out.

5. The amount of spinel or sillimanite, from magmas rich in magnesia or silica, depends wholly on the excess of alumina present. The same is also true of corundum.

6. The crystallization of corundum and spinel depends, not on the "basicity" of the magma, but only on the ratio of the bases (K_2O , Na_2O , CaO) to alumina. In the experiments, corundum crystallized out from magmas varying in silica from 0 (sodic-aluminate) to 13 (Rhyolite).

7. Rules 4 and 5 are not wholly true for those magmas which contain basic non-aluminous silicates like augite and olivine in any considerable quantity.

8. Corundum, spinel, sillimanite, and cordierite crystallize from silicate magmas according to the general laws governing crystallization from solutions.

In nature, magmas with alumina in excess occur, but are not very common. There are numerous cases of the primary occurrence of corundum, spinel, sillimanite, and cordierite in both plutonic and volcanic eruptives. The development of these minerals about inclusions and by contact metamorphism in clay slates is well known. These four minerals form a genetic group of close affinity in mode of origin. In the Urals there are numerous orthoclase-corundum rocks classed as pegmatites and syenites. Morozewicz describes fully a new type of great interest to petrographers, and of especial interest in connection with his experiments; the new rock he names Kyschtymite after the Kyschty district in the Urals: it consists of a medium-grained mix-

ture of idiomorphic corundum of pyramidal habit, with anorthite and biotite, and accessory dark green spinel of earlier generation than the corundum, with also apatite and zircon.

A number of remarkable experiments were made with acid magmas of the general composition of rhyolite or granite. By dry fusion at high temperatures it has frequently been demonstrated that tridymite is a more stable form of crystalline silica than quartz. In the case of the partial fusion of a quartzose block of granite, the quartz became transmuted into an aggregate of shingly tridymite flakes, and the same has been noted in nature in inclusions of granite in a porphyry. The presence of alumina in an acid magma was found to prevent crystallization, where a non-aluminous silicate mixture partially crystallized in the form of tridymite and prismatic silica (the latter of the unusual type described by Fouqué and M. Lévy). Vogt, in his exhaustive studies of furnace slags,¹ has called attention to the influence of alumina in "retarding" the crystallization of a glass or a slag, and this fact is well known to glass workers who add alumina to prevent the development of silicate crystals. With the aid of the theory of solutions, this influence is easily explained; in general, supersaturated solutions give large crystals, a lower degree of saturation gives small crystals, and unsaturated solutions under the same conditions develop no crystals at all. Alkaline silicate magmas are capable of dissolving alumina in large quantities; alumina possesses for the alkalies and more especially the alkaline earths a very strong chemical affinity, forming with them very stable and widespread natural compounds. Accordingly alumina in small amount dissolved in such a magma has only the effect of uniting with a portion of the bases in potential aluminosilicate form, and preventing them from crystallizing out as simple silicates which in the absence of alumina would easily saturate the solution. Morozewicz has demonstrated that a very large amount of alumina is required to saturate a solution to the effect of permitting crystallization of the aluminosilicates, as outlined above. When great excess of alumina is present, however, crystallization may be readily induced. Thus the expression, "retarding crystallization," is applicable only to access of alumina up to the critical point of saturation, beyond this its effect is that of an accelerator. The effect, in fine, of a small amount of alumina in a glass, is to produce aluminosilicate

¹VOGT, J. H. L.: Beiträge zur Kenntnis der Gesetze der Mineralbildung in Schmelzmassen und in den neovulcanischen Ergussgesteinen, Christiania, 1892.

molecular combinations, without saturation, and solidification takes the form of Van t'Hoff's "solid solution," namely an amorphous glass.

Rhyolite and trachyte magmas, with the Al_2O_3 percentage varying from 6 to 20, were fused in large masses under varying conditions, of cooling and for periods of a fortnight or more, solidifying invariably as structureless glass; the same magmas, it will be remembered, with an excess of alumina, developed the minerals of the corundum group with the greatest ease. The attempts were repeated with fluorides and phosphates added, but again without result. Finally success was obtained by adding 1 per cent. of tungstic acid to a rhyolite mixture of the following composition:

SiO_2	77.9
Al_2O_3	12.0
FeO	1.3
CaO	0.8
MgO	0.13
K_2O	3.3
Na_2O	4.6

A completely homogeneous glass was formed by the first fusion in the hottest part of the furnace, and partial crystallization was obtained by leaving the crucible at the inner mouth of the entrance chamber for fourteen days—a temperature estimated to vary between 800° and 1000° C. A heterogeneous mass showing flow structures resulted, yellow and white streaks alternating with bands of gray glass. In the microscope the white zones proved to be aggregates of myriads of bipyramidal quartz microlites, of hexagonal form, extinguishing parallel to the vertical axis, and optically positive. The yellowish streaks were much more abundant than the white, and proved to be composed of hexagonal plates of biotite of very perfect form and showing the truncated edges of the combination: (001) (111) ($\bar{1}\bar{1}\bar{1}$) (011). The absorption scheme, pleochroism, color, extinction and double refraction all agree with the properties of biotite. Many of the crystals show corrosion phenomena. Finally abundant aggregates of transparent prisms were observed, sometimes in spherulitic grouping, with extinction usually parallel and occasional twinning. These were believed to be sanidine. There were some other indeterminate colored grains and spicular crystals. The groundmass was essentially an isotropic glass, but showed a spicular microfelsitic structure. There had thus been reproduced by "dry fusion," with the aid of tungstic acid, an association.

of the essential minerals of granite—quartz, mica and acid feldspar. The influence of the tungstic acid the author believes to be as follows: after the temperature in the first melting has passed 1000° , neither tridymite nor quartz can form, because at these high temperatures the silica unites with alkalis to form a silicate, in which the tungstic acid is absorbed; it is believed that on lowering the temperature (the position of crucible which ultimately produced crystallization) the absorbed tungstic acid has the effect of decomposing these alkaline silicates and liberating the silica to form quartz. It is not known what compounds the tungstic acid finally forms. Dr. Morozewicz objects strongly to the use of the term “mineralizer,” and considers that much harm has been done to the progress of synthetic mineralogy by attributing all obscure reactions to the “mystical action of a mineralizer.” He insists that “agent minéralisateur” has no scientific meaning and should be banished from the vocabulary of the mineralogist. This would seem a little unreasonable, in view of the fact that he himself acknowledges that his only success in obtaining crystallization of the granitic minerals was due to the action of a small amount of tungstic acid, which he explains by what at best is only an incomplete hypothesis. Modern petrographers have not ascribed any “mystical” power to the compounds of tungsten, zirconium, boron, fluorine, etc., but have observed that these elements are minor but invariable accompaniments of the crystallization of coarse acid pegmatites. Morozewicz has only added confirmatory evidence from synthesis of the actual importance of these agents to promote crystallization in an acid magma, and whatever they be called, their influence, whether chemical or physical, cannot be denied. Possibly the word “crystallizer” would be more exact than “mineralizer.” It is certainly true, on the other hand, as Morozewicz points out, that this latter word has been much abused, and simple reactions have been allowed to pass unexplained as due to the action of a mineralizer, because a fluoride or a borate chanced to be in the equation.

The accompanying plates are reproduced to show the coarseness of crystallization obtained with basic magmas. The basic magmas are those still capable of dissolving free alumina, or, in other words, unsaturated. An enstatite basalt was produced from a mixture of three parts olivine, three parts labradorite, and one part augite. A large mass of this material was fused, a smaller quantity being separated for fusion with iron oxide (hematite) alone, the principal mass having a little

charcoal added to reduce the hematite present to the ferrous condition.

The smaller portion, after crystallization for twenty days, gave a well crystallized yellowish-brown mass. Pyroxene crystals could be seen with the naked eye. In the vesicles of the slag were remnants of unmelted hematite, as well as newly crystallized hematite flakes and brilliant spicular pyroxene crystals, sometimes 1^{mm} long. These crystals showed distinct prismatic, pinacoidal and pyramidal faces, pleochroism, and parallel extinction. In thin section, as shown in Plate IV, Fig. 2, distinct porphyritic structure was observed, with idiomorphic enstatite and olivine in a groundmass consisting of monoclinic pyroxene, plagioclase, magnetite, and a small quantity of glass. The olivine was in short crystals, completely transparent and colorless, of very strong double refraction and parallel extinction. The greater part of the olivine crystallized in spherical concretions. The plagioclase of the groundmass showed twinning with extinctions varying from 10° to 27°, hence, a labradorite. Its crystallization was earlier than the other components of the groundmass. The augite formed aggregates of prisms partly as small phenocrysts, but principally in the groundmass. The order of crystallization was thus olivine, enstatite, monoclinic pyroxene, labradorite, magnetite and augite, glass. The larger mass (over 100 pounds), gave also an enstatite basalt (Plate IV, Fig. 1) with crystals of both orthorhombic and monoclinic pyroxene, and olivine, in a colorless groundmass. This groundmass appeared to be a completely homogeneous colorless glass. Pieces of this glass, heated three days at the temperature of red glow without melting, acquired a trachytic crystalline habit of rough surface, and lost their original glassy luster. The groundmass by this heating, developed a crystalline mixture of tiny plagioclase and augite microlites, showing that long continued application of heat to a supersaturated solution, even in solid condition, could bring about crystallization. In order to test the temperature necessary to produce crystallization, the following experiments were devised. Six crucibles were filled with fragments of this slag and placed in a row between the hottest part of the interior of the furnace and the middle of the entrance chamber. At the end of a month it appeared that the innermost four crucibles contained only glass, which had strongly corroded the crucible walls; while in the fifth and sixth crucibles (those within the chamber) crystalline products had formed. An investigation of preparations from these crucibles showed that the order of crystallization of the component minerals was the same

throughout and forms a constant function of the chemical composition of the magma. Period of crystallization and temperature have an important influence only on the structure of the resulting rock.

The second plate here reproduced (Pl. VII) shows the products of crystallization from an anorthite-nepheline magma without magnesia, consisting principally of corundum, anorthite, and nepheline. This was fused in large masses, producing a well crystallized gray rock. In the microscope the principal mineral is seen to be plagioclase prisms in long rectangular form with distinct cleavage and multiple twinning. Between the plagioclase laths is a groundmass consisting of nepheline, magnetite and glass. The physical properties of this plagioclase are essentially those of anorthite ($An_6 Ab_1$) with the following chemical composition :

SiO ₂	46.5
Al ₂ O ₃	34.6
CaO	17.3
Na ₂ O	1.6

Corundum is enclosed in the plagioclase in the form of circular plates. The groundmass contains many small microlites of magnetite, forming sometimes a rectangular network. Nepheline occurs in short, hexagonal prisms and irregular masses, forming the greater part of the groundmass. There are, in addition, pleochroic yellowish corroded crystalline flakes, which are probably lepidomelane. The glass base occurs in variable quantity in different parts of the crucible.

The systematic subdivision of aluminosilicate magmas, in relation to these experiments, deserves especially thorough examination. The greater part of known eruptives on the surface of the earth belongs to the aluminosilicate group of magmas. The principal and most stable components of magmas are silica and alumina, while the bases are variable and easily replace each other to form both minerals and rocks. Both SiO₂ and Al₂O₃ are capable of crystallizing out in free form by supersaturation, and both (according to the experiments of Thugutt¹ and the theoretical conception of Wernadskij²) are capable of playing chemically the part of acids. Silica and alumina are thus conceived to have an analogous systematic significance in the classification of eruptive magmas, granite being a magma supersaturated with silica, and

¹ ST. THUGUTT, Zur Chemie einiger Aluminosilicate. N. J. f. M., 1895, B.-Bd. IX,

² W. WERNADSKIJ, Ueber die Sillimanitgruppe, sowie die Rolle der Thonerde in Silicaten. Moscow, 1891 (Russian).

corundum-syenite a magma supersaturated with alumina. Alumino-silicate magmas are thus divided into two great analogous groups, each of which is subdivided into three types, as follows :

GROUP A

1. Magmas supersaturated with Al_2O_3 .
2. Magmas saturated with Al_2O_3 .
3. Magmas not saturated with Al_2O_3 .

GROUP B

1. Magmas supersaturated with SiO_2 .
2. Magmas saturated with SiO_2 .
3. Magmas not saturated with SiO_2 .

In both groups type 2 is the same, a syenite or trachyte magma, simultaneously saturated with both alumina and silica. There are thus five principal types in all, as follows :

1. Magma supersaturated with alumina : corundum-syenite, bearing alkaline feldspars, and kyschymite bearing lime-soda feldspars.
2. Magma supersaturated with silica : granites, rhyolites, quartz-diorites, dacites, etc.
3. Magma saturated simultaneously with alumina and silica : mica-syenite, trachyte, mica-diorite, and mica-andesite. In this magma the aluminosilicates are the essential minerals. The pure metasilicates and orthosilicates are accessory or absent.
4. Magma not saturated with alumina : gabbro, basalt, diabase pyroxenite and other basic rocks. Obviously this magma is also not saturated with SiO_2 .
5. Magma not fully saturated with SiO_2 : elaeolite-syenite, phonolite, leucitite, etc.

The magma types 4 and 5 are not identical. A biotite-elaolite-syenite can be saturated with Al_2O_3 and not fully saturated with SiO_2 . In the same way some nepheline rocks may be considered as saturated with Al_2O_3 , but do not contain sufficient silica to develop free quartz. In the above scheme it is of course obvious that the rocks belonging to the first type of Group A are least widespread according to our present knowledge of the geology of the earth, and will be discovered, in the opinion of the author, in greater quantity in the future.

It will be seen that in these experiments all the essential minerals of the "neovolcanic lavas" have been reproduced with the exception

of hornblende, and also many rock structures of characteristic habit. These structures are proved to be the result of external conditions of crystallization and also of chemical composition, both in qualitative and quantitative sense. The order of crystallization of the individual minerals depends on no one factor, such as "fusibility" or "acidity," but is the result of a complex equation in which, perhaps, the most important element is the ratio of the quantities of the several compounds dissolved in and composing the solution. One and the same compound can begin to crystallize out sooner or later than another according to the amount which is present. The order of crystallization is different in different magmas, and different substances have different capacity for forming saturated solutions in an aluminosilicate magma. In certain cases temperature has an important influence: magnetite, for instance, forms a saturated solution best at temperatures below 1000° C. At higher temperatures it crystallizes out after olivine. Anorthite crystallizes out more easily at a higher temperature (over 1000°). The process is obviously much complicated by the changes in the magma itself as a solvent, by progressive crystallization of the compounds composing it.

The following are a few of the principles defined by observations up to this date; but final laws of silicate saturation can only be attained by many experiments of character similar to these, which, as in the advanced synthetic work of organic chemistry, shall have thrown light on the structural formulae and atomic relationships of the silicates.

1. Corundum, spinel, sillimanite, and cordierite in magmas supersaturated with alumina, are the first products of crystallization. Spinel and sillimanite crystallize before corundum.

2. Magnetite at a temperature below 1000° crystallizes out in proportion to the supersaturation of a solution with ferric iron and to the amount of other iron compounds. It crystallizes sometimes before and sometimes after augite and plagioclase according to their relative amounts.

3. The different orthosilicates of the type Me_2SiO_4 (olivine, etc.) crystallize first from a magma not supersaturated with alumina.

4. Rhombic pyroxene develops earlier than augite, if the molecular ratio of magnesia (and ferrous iron) to lime is about three or more.

5. The crystallization of augite is very variable.

6. In a magma with h  yne (33 per cent.) in excess of anorthite (23 per cent.) the h  yne crystallizes first.

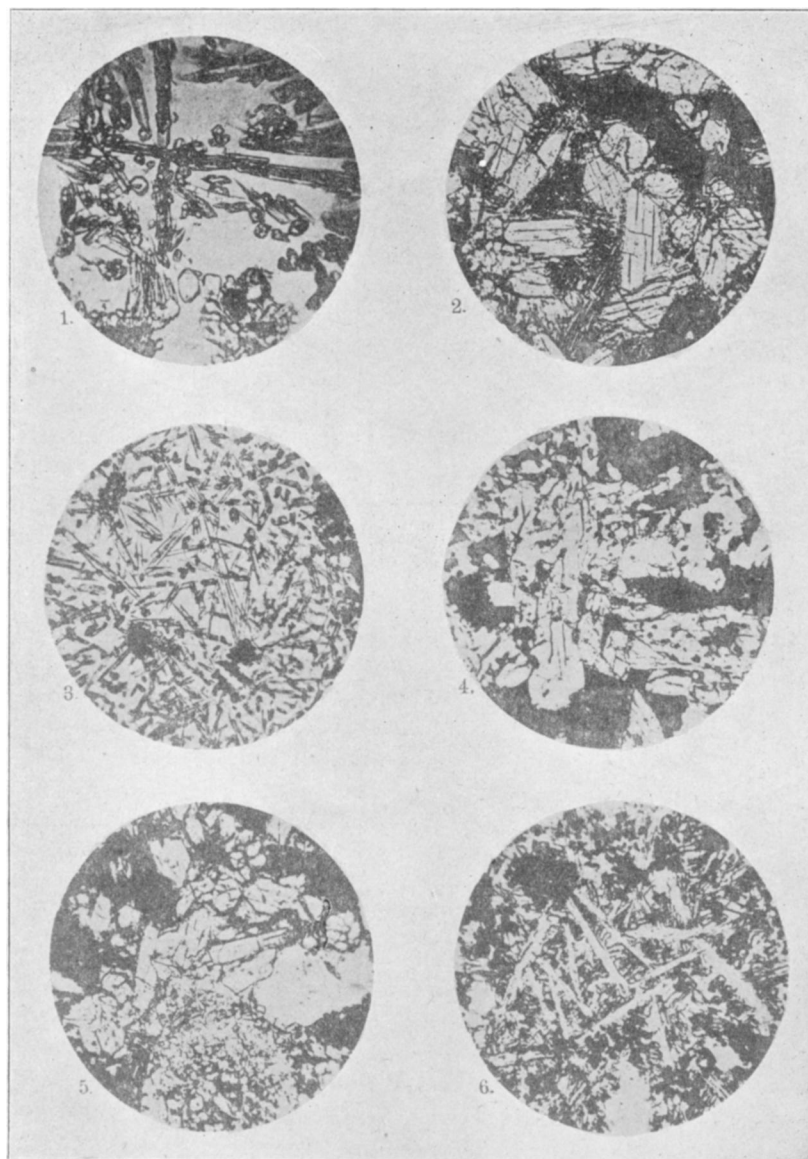
7. In a magma with the ratio of bases to alumina greater than 1, melilite crystallizes after olivine and simultaneously with anorthite.

8. Plagioclase begins to crystallize after olivine, and in many cases after augite, according to the amount present. Nepheline is one of the latest products of crystallization, forming usually a groundmass product between plagioclase laths (mesostasis).

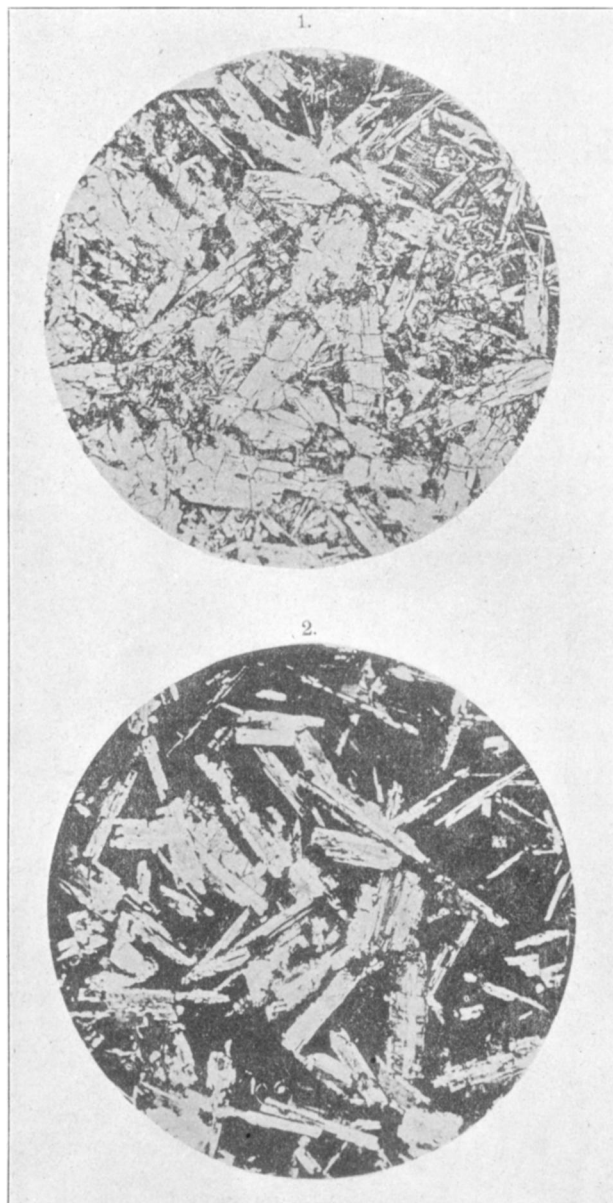
10. The glassy groundmass represents an uncrystallized solid solution and frequently has the composition ($\text{MeO} \cdot 2\text{SiO}_2$) of Lagorio's "normal glass."

With respect to the question of magmatic differentiation, Morozewicz favors rather the hypothesis of one primary magma, chemically differentiated for a single region by means of processes determined in the main by the laws which govern solutions. In many of the experiments described a single crucible showed remarkable variations in structure, coloring, and composition locally. This was especially true of magmas rich in the alkaline earths. In a 100-pound mass, consisting chiefly of alkaline augite, the lower portion showed throughout a higher specific gravity than the upper, with much magnetite below and none above. In common glass-melting, separation of layers of higher specific gravity in the bottom of the crucible has been noticed, these being especially rich in iron, lime, and magnesia. A mass of granite weighing two pounds was melted in large pieces in the hottest part of the furnace, and allowed to glow at the inner entrance of the chamber for five days, producing a glassy mass below with quartz grains unmelted and partially altered to tridymite above. These quartz grains had apparently been floating in the glass; the glassy portion appeared fully homogeneous and was of uniform color; in fact, however, careful separate analyses of the upper and lower portions of the glass showed not only that the upper portion was richer in silica, but that the ratio of the bases was different. Thus Fe_2O_3 showed in the lower layers an increase of .8, MgO of .7, CaO of .4, and alumina of .2. The specific gravity of the lower part was about .1 greater than the upper. The silica percentage of the upper part was 73.65, of the lower part only 59.20. Thus the iron and alkaline earths settled to the bottom, and the silica and alkalis remain in excess above. It is significant that these substances (FeO , MgO and CaO) which form the lower stratum of glass, are the ones which crystallize out earliest from silicate magmas.

In conclusion the reviewer would call the attention of geologists



SYNTHETIC EXPERIMENTS BY MOROZEWICZ



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and petrographers to the accompanying plates reproduced from this remarkable monograph, and to the importance of careful study of the results of such experimentation in connection with research in the field. Dr. Morozewicz has written the results of his elaborate synthetic studies in most compact and readable form, the work being contained in 225 pages systematically arranged, well indexed, with each chapter carefully summarized as well as the whole work. He has shown that the synthetic production of rock-making minerals is possible under conditions attainable in any of our large cities, and his work should be a stimulus to further endeavor of the same sort. Analytical work alone is no more capable of solving many difficult problems connected with the origin of the igneous rocks and of ore deposits than are the methods of microscopical petrography. Morozewicz has shown that the same synthetic treatment is applicable to the chemistry of the silicates that has been used for years in the case of the hydro-carbon compounds.

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PLATE III.

Fig. 1. Enstatite-basalt, first stage: olivine, enstatite, monoclinic pyroxene, glassy groundmass; enlarged $\times 60$.

Fig. 2. Enstatite-basalt, second stage; micro-porphyritic structure: large enstatite crystals in a groundmass which consists of augite, labradorite, olivine, and magnetite; enlarged $\times 60$.

Fig. 3. Normal basalt, first stage; augite and magnetite microlites in glassy groundmass (hyalopilitic); enlarged $\times 60$.

Fig. 4. Normal basalt, second stage: great augite masses with inclusions of olivine and magnetite; brown groundmass; enlarged $\times 60$.

Fig. 5. Enstatite-basalt: olivine concretions seen below; enlarged $\times 60$.

Fig. 6. Basalt without olivine, ophitic structure: long plagioclase prisms with augite in the interspaces; black grains of spinel and magnetite; enlarged $\times 60$.

PLATE IV.

Fig. 1. Anorthite-nepheline magma: large anorthite crystals with cleavage cracks and multiple twinning; in the groundmass occurs nepheline, arborescent magnetite forms, etc.; ordinary light, enlarged $\times 15$.

Fig. 2. The same between crossed nicols in polarized light.